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DENISON V. POWER GEAR

Your Client: Power Gear
Client File No.: 8093.13-337
Date of Loss: February 12, 2011

Crane File No.: C8190
Crane Descriptor: MET – POWER GEAR – DENISON

Prepared for:

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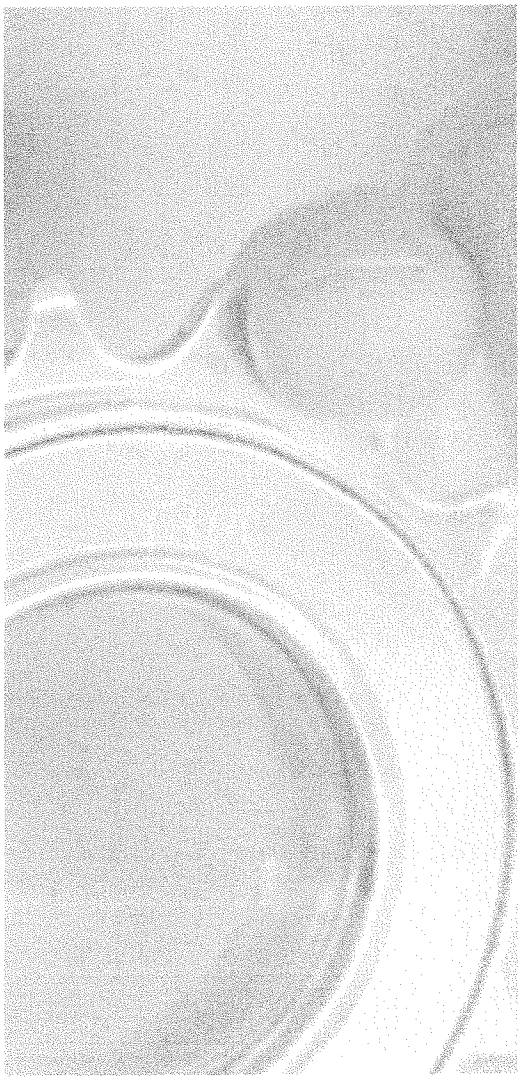
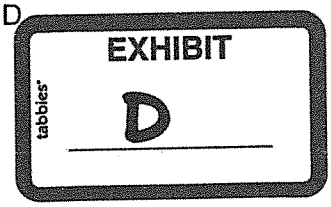


I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

Jeffrey A. Pfaendtner, P.E., Ph.D.
License No.: 46363
Date: June 19, 2015



SUMMARY AND BACKGROUND

This report involves an incident that occurred on or about February 12, 2011 that is claimed to have involved the failure of a set of RV steps and alleged resultant injuries to Ms. Nedra Denison. Crane Engineering, Inc. was engaged on or about January 3, 2014 by Mr. Craig Erickson to investigate and evaluate the subject RV steps. The scope of my investigation and analysis is directly related to the metallurgy and fracture mechanics of the subject RV steps and the crack and plastic deformation observed in a component commonly referred to as a "link" or "linkage" in this litigation. This component is called the "LEG DRIVE SHRT FAB" in its engineering drawing (Drawing No. 3252084 Rev 2). This report, prepared at the request of Mr. Erickson, represents the results of my investigation performed to date. This report includes a critical review and rebuttal of the methods employed, assertions and opinions of plaintiff's expert Dr. Tariq Khraishi[1][2][3].

A listing of the materials reviewed as part of my investigation and analysis is included as an addenda to this report. A companion report (dated June 19, 2015) was prepared by Mr. Christopher J. Brand, P.E. that deals with the mechanical engineering aspects of this matter.

I am a Materials Engineer for Crane Engineering, Inc. I received a B.S.E. in Materials Engineering from the University of Pennsylvania in 1990 and a Ph.D. in Materials Science and Engineering from the University of Pennsylvania in 1998. I am a licensed Professional Engineer (PE) in the State of Minnesota. I have over 20 years of experience in the field of materials science and engineering, and metallurgical engineering. Crane Engineering currently charges $295 per hour for my services. My curriculum vitae, which includes my professional qualifications and a list of publications are included as attachments to this report.

INSPECTIONS

The subject RV steps were received at Crane Engineering on May 27, 2014 and stored in its artifact storage facility. All inspections and analysis of the subject RV steps at Crane Engineering were done in a non-destructive manner.

The steps were visually inspected and photographed (see Figure 1, Figure 2, Figure 3, and Figure 4). As indicated in these photographs, a crack was found in the left-side link (left side as one would climb the steps). Both left-side and right-side links were observed to be deformed. Higher magnification images of the left-side and right-side links are shown in Figure 5 and Figure 6, respectively.

The crack opening in the left-side link is shown from an oblique angle in Figure 7 in relation to the weld bead. Images of the corresponding location on the opposite weld of the left-side link are shown in Figure 8 and Figure 9, respectively (Figure 9 is photograph #9918 supplied by Dr. Khraishi and put forward as an example of an "ingress" as referred to repeatedly in his report and deposition). Figure 10 and Figure 11 are representative images of the corresponding weld locations on the right-side link.

Figure 12 is a higher-magnification image of the subject crack in the left-side link taken with a Keyence VHX-600 digital microscope. Here it can be seen that the geometry of the crack opening is in the shape of a "V", the significance of which will be discussed below.

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[1] T. Khraishi email dated March 31, 2014
[2] T. Khraishi report dated March 11, 2015
[3] T. Khraishi deposition dated May 19, 2015

ANALYSIS

The subject RV steps were received at Crane Engineering in the condition depicted in Figures 1-4. The steps arrived in the closed position (e.g., Figures 1, 3, 4), but were functional in that they could be easily opened by hand as shown in Figure 2. All linkages and joints were found to be operational. Dr. Khraishi characterized the event that led to Ms. Denison's injuries as "...the RV steps collapsed causing her to fall"[4]. The use of the word "collapse" is a highly inaccurate way of describing the steps in their post-incident condition. A common engineering use of this term is generally associated with the description of a catastrophic event involving something such as a building or other structure falling down, or giving way, such that its original form or structure is no longer intact. In stark contrast to this definition, the subject RV steps are still intact and functional. In fact, the Denisons continued to use these steps for some time after the incident[5]. The only readily apparent damage or deformation to the RV steps was to the two links shown in Figures 5 and 6.

The two links exhibit visible (macroscopic) permanent deformation (presumed to have resulted from the subject incident). This type of permanent deformation in metals is termed "plastic deformation" or "plasticity" in the fields of metallurgical and mechanical engineering. Central to Dr. Khraishi's opinion of a material and/or design defect[6] in the subject welds, material or manufacture is the claim that the material exhibited "brittle" fracture behavior[7] as opposed to the more desirable "ductile" behavior[8]. However, as described in one widely distributed engineering undergraduate textbook on the topic[9], "...ductile failure is simply one that exhibits visible plasticity prior to failure, whereas in this particular nomenclature scheme a *brittle failure* does not". And according to one of Dr. Khraishi's own references cited in his report[10], also a widely used undergraduate materials textbook, "[Ductility] is a measure of the degree of plastic deformation that has been sustained at fracture. A metal that experiences very little or no plastic deformation upon fracture is termed *brittle*". Based on the visible macroscopic plastic deformation to both links, and in accord with these references, the observed crack in the left-side link is undoubtedly the result of ductile fracture.

Furthermore, the geometric shape of the crack itself is evidence of the subject crack having formed under conditions of ductile fracture. As shown in Figure 12, the crack opening exhibits a distinct "V" shape that is a hallmark of ductile fracture (and is a direct physical consequence of the underlying microscopic deformation mechanisms of ductile failure). This important metallurgical concept is illustrated in the schematic diagram depicted in Figure 13, which was taken from a chapter section entitled "Ductile Fracture" from the second engineering reference cited by Dr. Khraishi[11]. In contrast "For brittle fracture, the fracture surface is relatively flat and perpendicular to the direction of the applied tensile load"[12]. Clearly, the subject crack does not meet any of the cited requirements to be considered a brittle fracture.

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[4] TK report, p. 1
[5] Alan Denison deposition, p. 63
[6] TK report, p. 1
[7] TK depo, p. 58, 107, 108, 111, 112
[8] TK depo, p. 113
[9] "Deformation and Fracture Mechanics of Engineering Materials", by Richard W. Hertzberg *et al.*, 5th Edition, Wiley (2012), p. 268
[10] "Materials Science And Engineering: An Introduction", by William D. Callister, Jr. *et. al.*, 8th Edition, Wiley (2010) p. 166
[11] "Fracture Mechanics: Fundamentals and Applications", by T.L. Anderson, 3rd Edition, CRC Press (2005) p. 233
[12] *op. cit.* Callister, p. 271

Based on his incorrect characterization of the subject crack as being a "brittle" fracture, Dr. Khraishi then speculates on the underlying metallurgical causes of the brittleness[13]. Based solely on the false premise of brittle fracture, he then conjectures to conclude the further existence of one or more harmful microscopic metallurgical features in the steel links (i.e., embrittlement, martensite, formation of brittle phases), or that an "improper heat treatment of the weld area" was performed[14], and assigns them a causal role in the observed cracking of the left-side link. He cannot, however, say with any certainty which of these features is actually responsible for the brittle crack he claims[15]. He further speculates that "maybe cheap material" was involved[16], or that the "material type is prone to martensite"[17] as causes for the formation of these hypothesized harmful metallurgical features. From his testimony it is obvious that Dr. Khraishi does not know the specific type of welding performed in the manufacture of these steps, or whether the steps receive a post-weld heat treatment[18], nor does he know the type of material (steel) from which the steps are made, but nonetheless concludes it to be brittle[19]. In a contradictory statement, however, he offers, "…mild steel, for example, is considered ductile."[20] Ironically, the cold-rolled steel from which the link was fabricated is, in fact, a form of mild steel, and is therefore, ductile by his own assessment.

Related to Dr. Khraishi's claims about embrittlement, or brittle phases, is his assertion that the crack occurred in the weld "heat affected zone"[21] and that this is "where the embrittlement happened"[22]. These assertions appear to also form the basis of his claim of "defective craftsmanship/fabrication and/or materials"[23]. However, Dr. Khraishi cannot possibly know the exact location of the heat affected zone (and whether the crack is contained within it), nor can he know of the very existence of all of the cited microscopic metallurgical features (i.e., embrittlement, martensite, formation of brittle phases) as these features can only be discovered via destructive metallurgical testing. This is testing that Dr. Khraishi knew could be done, but did not do, as he claimed, "there is no need for it"[24]. But yet, he acknowledges that destructive testing with some form of microanalysis would be required to determine the presence of martensite or other brittle phases[25]. In reality, however, the macroscopic physical features of the subject links and the subject crack demonstrate this to be a ductile fracture, which in itself, is strongly indicative of the absence of these metallurgical features.

Throughout his report and deposition, Dr. Khraishi made frequent reference to an apparent, and allegedly harmful, weld-induced geometric feature he termed "ingress". This word is not a term of art in mechanical or materials/metallurgical engineering, and it is therefore difficult to understand what is meant by it, or what it describes. Less frequently, he used the terms "small crack" and "notch" in association with "ingress". These two alternate terms do connote a geometric feature that would act as a "stress riser", something that would facilitate the formation of a crack in a component at stresses lower than those, which would be necessary in the absence of the stress riser. However, careful

[13] TK depo, p. 50, 104, 142
[14] TK depo, p. 141
[15] TK depo, p. 141
[16] TK depo, p. 168, 175
[17] TK depo, p. 142
[18] TK depo, p. 137
[19] TK depo, p. 58
[20] TK depo, p. 109
[21] TK report, p. 1
[22] TK depo, p. 101
[23] TK report, p. 1
[24] TK depo, p. 136
[25] TK depo, p. 103-104

inspection of both links (visually and with the aid of a digital microscope) reveals no stress riser that would have contributed to the formation of the subject crack (see Figures 5-11). Dr. Khraishi does point to one of his photographs (# 9918; Figure 4 in his report) as an example of an "ingress" (in his report Dr. Khraishi incorrectly attributes this image to the "right-side of the steps", whereas the small physical attributes of the location represented in this image clearly indicate that this photograph was taken of the cracked link on the left-side of the steps). However, his photograph, shown in Figure 9, does not reveal any unusual geometric feature that might act as a stress riser under the loading, or stress, conditions present in the subject links. This photograph does reveal what appears to be a microscopic crack-like feature at the interface between the weld bead and the edge of the link. This tiny feature may have originated in the welding process (e.g., it is an artifact of the termination of the weld bead), or it formed as a result of the incident itself. Regardless of whether this feature existed prior to the incident in which Ms. Denison was injured, its physical orientation is perpendicular to that of the subject crack, and therefore, is unlikely to have formed under the same circumstances. Given its orientation with respect to the primary stresses on the link, this small feature is inconsequential and benign with respect to the mechanical behavior and strength of this welded joint. In summary, Dr. Khraishi claims the existence of a harmful "ingress" feature associated with the welds, but careful inspection of the welds and links demonstrates that no such harmful geometric feature actually exists.

In association with the alleged "ingress" feature, Dr. Khraishi claims the existence of rust at, or near, the crack opening, and further claims this rust as evidence that the "ingress" was a feature caused by the welding process itself[26] (despite having provided no definitive evidence of the actual existence of the "ingress" feature as discussed above). Closer examination of the fracture surface (see Figure 14), however, reveals sporadic amounts of apparent rust, with areas closest to the likely initiation point appearing relatively free of rust in comparison to areas deeper within the crack. His already unsubstantiated conclusion of the existence of a pre-existing crack-like feature (i.e., "ingress") is not changed or improved by an additional claim that he can date the existence of any portion of the crack back to the original manufacture of the steps based on observed existence of rust, especially when any observation of rust is made several years after the incident. Steels of this type by themselves have a low resistance to surface corrosion, and can form superficial rust on the surface by simple exposure to ambient humidity. Therefore, it is impossible in this situation to assign any meaning to any observed rust.

In strong contradiction to the assertions and opinions of Dr. Khraishi, the physical evidence (the ductile fracture and the associated macroscopic plastic deformation of the left-side link) is fully consistent with a properly designed and manufactured RV steps that employed proper materials and proper welding. In contrast to Dr. Khraishi's claims, the observed plastic deformation and shape of the crack in this failure are evidence that the crack formed as a direct consequence of a one-time event in which the RV steps were overloaded. That is, the metallurgical aspects of this failure indicate that the steps were simply loaded beyond the capacity to which they were designed.

If one were to hypothesize the existence of the alleged harmful metallurgical features, and assume a resultant failure load on the steps equivalent to Ms. Denison's body weight (as inferred from Dr. Khraishi's arguments), then it stands to reason that the steps would have failed the first time Ms. Denison used them after the purchase of the RV. The metallurgical features conjectured by Dr. Khraishi would have existed from the time of manufacture of the steps, and there is no plausible physical mechanism by which these features could have worsened over time. Likewise, there is no plausible time-dependent mechanism consistent with the facts by which the subject link in the steps

[26] TK report, p. 1

could have weakened over time. The amount of observed corrosion (rust) is cosmetic and would not have impacted the strength of the steps to any measurable degree. Dr. Khraishi, however, does appear to intimate the possibility of *fatigue* being responsible for a progressive weakening of the subject link (without actually suggesting it by name)[27]. However, this too is not in evidence. No discernable fatigue striations are visible on the exposed fracture surface (see Figure 14) and the overall geometry of the crack opening (i.e., V-shape) is inconsistent with the nucleation and propagation of a fatigue crack at this location. That is, no evidence exists for any accumulation of damage or other weakening of the steps, or subject link, over time. Therefore, it may be concluded that no latent, or pre-existing, harmful metallurgical features could have been created through the welding and other fabrication processes by which the steps were originally manufactured.

The Scientific Method is the only commonly accepted, systematic and objective methodology for conducting a forensic failure investigation such as the one at hand. Dr. Khraishi claims to know the steps of the Scientific Method[2829] and to have used the Scientific Method in his investigation[30], and further states "my opinion was based on evidence and the Scientific Method"[31]. However, the investigative process that is embodied by his report and deposition testimony, and through which he arrived at his opinions and conclusions, is inconsistent and in direct violation of the Scientific Method. The Scientific Method requires the collection of data; Dr. Khraishi admits to having done no testing or measurements, nor saw the need for testing[32]. The Scientific Method requires the analysis of data; Dr. Khraishi performed no calculations or numerical simulations (a task for which he is well-equipped), or other analysis. The Scientific Method requires the development of hypotheses (of failure) that should be based on empirical data that is collected. Dr. Khraishi's hypotheses are not based on collected, factual data; rather they are based on the conjectured existence of certain data. He claims, "...for me, I don't need to do testing. It's very clear for me the causes of instability and falling"[33], and "I did not do microscopic-type testing, because, again, that's not important for what caused the fall"[34]. But, yet, these statements belie the central theme of his assertions, which revolve around the very existence of microscopic metallurgical features. Finally, when properly executed, and a sufficient number of facts have been uncovered and analyzed, the Scientific Method may yield a "final hypothesis". The final hypothesis is one that has been tested and is one determined to be uniquely consistent with the facts and with the principles of science[35]. Dr. Khraishi's hypotheses cannot be considered final as they are not uniquely consistent with the facts (he did not measure, test or analyze to find the facts), nor did he consider alternate hypotheses that might fit the criteria of being termed "final". In this regard he claims, "I don't have to consider anything that doesn't come to mind."[36]

In summary, Dr. Khraishi's theories of failure are, in totality, based on the assumption of facts not in evidence. His theory of brittle failure is directly contradicted by the observed fact of macroscopically visible ductility and geometric features associated with the crack opening that are direct signs of ductile failure. Dr. Khraishi did no testing, performed no calculations and employed no systematic, objective

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[27] TK depo, p. 171
[28] Exhibit 42
[29] TK depo, p. 96, 99-100
[30] TK depo, p. 96, 121, 163
[31] TK depo, p. 172-173
[32] TK depo, p. 120, 126, 135
[33] TK depo, p. 126
[34] TK depo, p. 135
[35] NFPA 921, 2014 Edition, Chapter 4
[36] TK depo, p. 135

methodology in arriving at his opinions. His opinions and conclusions are therefore, unreliable and are inconsistent and in violation of the Scientific Method.

An alternate hypothesis, not considered by Dr. Khraishi, exists that is consistent with the facts and provides an explanation for the present damaged condition of the subject RV steps. This hypothesis involves failure of the steps by a downward force that overloaded the steps. As demonstrated by the calculations and numerical simulations performed by Mr. Brand and presented in his report, the cracked condition of left-side link is consistent with the application of a force on the steps that is several times the likely weight of Ms. Denison. In fact, the location of failure predicted by Mr. Brand's simulation is the exact location at which failure occurred in the link. And the macroscopic ductile appearance of the link and crack are what would be expected from the steel from which the link was fabricated. The damage to the steps was not the result of any material or manufacturing defect, rather it was the direct result of an overload event that exceeded the load capacity of the subject RV steps.

CONCLUSIONS AND OPINIONS

Based on my education, training and experience as well as the investigation and analysis outlined herein, I hold the following conclusions and opinions to a reasonable degree of engineering certainty.

1. The subject left-side link exhibited a crack that formed under conditions of ductile overload. Dr. Khraishi's characterization of the crack as being the result of "brittle fracture" is in no way substantiated by the physical evidence, and is contradicted by his own engineering references.
2. Without performing any testing Dr. Khraishi postulates the existence of various harmful metallurgical features in the subject link (i.e., embrittlement, martensite, brittle phases) and further declares the crack to be located in a "heat affected zone". Based on this conjecture he concludes the steps to be defective in "craftsmanship/fabrication and/or materials". However, based on the level of investigation he performed (visual inspection only) and his reliance on facts not in evidence and a general lack of meaningful data, his opinions and conclusions cannot rise above the level of speculation.
3. Dr. Khraishi did no testing, performed no calculations and employed no systematic, objective methodology in arriving at his opinions. His theories of failure are based on the assumption of facts not in evidence. His opinions and conclusions are therefore unreliable and are inconsistent and in direct violation of the Scientific Method.
4. The damage to the steps was the direct result of an overload event that exceeded the load bearing capacity of the subject RV steps. The crack formed in the exact location predicted by the numerical simulations of Mr. Brand and its geometric and metallurgical features are fully consistent with such an overload event.

The conclusions and opinions formulated during this investigation and presented herein are based on information available to date. Crane Engineering reserves the right to supplement or otherwise amend this report should other information become available.

Respectfully submitted,

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I hereby certify that this plan, specification, or report was administratively reviewed by me and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

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